PHYSIOLOGICAL ASPECTS OF ELECTRICAL ACCIDENTS IN THE COAL-MINING INDUSTRY

BY S. J. DAVENPORT AND G. G. MORGIS

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INTRODUCTION

The tremendous increase in mine mechanization since 1929 has increased markedly the application of electric power in and about the coal mines of the United States. Cutting, drilling, and loading machines have replaced hand-mining methods in many mines. As a result, expansion of the gathering haulage has necessitated introduction of extensive feeder, trolley, and other power wires. (1)[3]

In spite of this vast mechanization the fatality rate from electric shock has been on the decline. However, there are still too many accidents, and efforts to eliminate electrical hazards cannot be relaxed. It is hoped that an acquaintance with the physiological aspects of electrical accidents will make workers and management aware of the lurking dangers of this very common and extremely dangerous form of energy.

SUMMARY

The paper presents a brief résumé of the fatalities from electric contact accidents in the bituminous-coal and anthracite mines of the United States for the 45-year period 1906-50. It is interesting to note that during the 10-year period 1941-50 there was an average of 27.9 fatalities per year, which is a reduction of 54.1 percent compared with the total average of 60.9 fatalities for the 45-year period.

Seven factors for determining effects produced by electricity when it flows through the body are discussed.

Physical reactions to the wide range of current values are grouped in eight classifications and described. A detailed summation is presented of such physiological effects of electric shock as blood pressure, hemorrhages, and damage to the nervous system.

Treatment for shock by artificial respiration and drug administration and measures for the prevention of electrical accidents in coal mines are reviewed.

OCCURRENCE

Electrical accidents in coal mines are generally listed as occurring underground, on the surface, in stripping or open-cut mining, or in dredge operations.

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[3] Numbers in parentheses refer to bibliography at end of circular.

Underground electrical accidents are classified as:

1. Those resulting in explosions of gas or coal dust ignited by electric arc. (During the 12-year period 1931-42 more than a third of the explosions were of electrical origin). (2)

2. Premature detonation of explosives from an electric wire or stray currents.

3. Those not resulting in explosions (electric contact accidents).

For the purpose of this paper, only electric contact accidents are considered. During the 45-year period 1906-50 there were 2,739 fatalities caused by electricity in the bituminous-coal and anthracite mines of the United States - an average of about 60.9 fatalities a year.(3) Since 1937, however, the number of fatalities has decreased somewhat. From 1937-46 there were 406 fatalities from electric contact accidents in underground mines; 25 fatalities in stripping and open-cut mining; and 47 on the surface (including tipple, breaker, shops, and yards). (4) Thus, over this period of 10 years, 478 deaths resulted from electric-contact accidents - an average of about 47.8 deaths each year. During the 10-year period 1941-50 there were 279 fatalities due to electric contact which is a yearly average of 27.9 for the period. This average of 27.9 shows a reduction of 54.1 percent when compared with the total average of 60.9 for the whole period. The data for the last 2 years (1949-50) show a still greater reduction - 12 fatalities for 1949 and 14 for 1950. Although recent reductions in fatalities from electric shock are encouraging, the potential hazards are still present and will increase with greater mechanization of the mines.

POWER-FREQUENCY CURRENTS AFFECTING HUMAN BEINGS

The following factors must be considered in determining the effects produced by electricity when it flows through the body. (5)

1. Type of circuit and its frequency.
2. Voltage of the circuit.
3. Resistance of the body.
4. The current that flows.
5. Pathway of the current through the body.
6. Duration of the contact.
7. Phase of heart cycle at the instant the shock occurs. (included by Dalziel). (6)

Type of Circuit and Its Frequency

Electric circuits may be either direct or alternating current. Alternating currents may vary in frequency, and the muscular contraction usually resulting from contact with an electric circuit is greater on alternating- than on direct-current circuits. Low-voltage direct-current circuits are much less dangerous than alternating circuits of the same voltage.

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Voltage of the Circuit

High-voltage circuits are recognized as hazardous, but low-voltage circuits also are dangerous, and fatalities have occurred on commercial frequency circuits carrying as low as 46 volts. Dalziel and Lagen (7) found, by tests with open-circuit voltages from 5 to 9,720 volts, that sensations and muscular reactions are proportional to the current and not the voltage. This confirms the opinion that current and not voltage is the proper criterion of shock intensity.

Resistance of the Body

The epidermis (the outer layer of the skin) offers the best protection against electricity. It is horny, contains no blood vessels or nerves, and is a poor conductor. The inner skin or derma is rich in blood capillaries and nerves and is a good conductor. (5)

The resistance of the dry epidermis is high. The calloused palm of a worker may reach the resistance value of 15,000 ohms per square inch; however, when thoroughly wet its resistance may fall to less than 1/100 of its dry value. Once the current penetrates the epidermis the resistance of the body to the flow of electricity is low. Skin resistance has many other peculiar properties; it increases during sleep, it is high on paralyzed regions of the body, varies with the applied voltage, and blisters increase the hazard of low-voltage shocks. The heat produced by a 120-volt circuit will form blisters within a few seconds. A slight cut or abrasion of the skin also lowers the resistance greatly. (8)

The Current that Flows

The current that flows through the body when contact is made with an electrical circuit is determined by Ohm's law, which states that the current in amperes equals the applied volts divided by the resistance of the circuit in ohms. It is the electric current flowing through the body that determines to a large extent the resultant injury. (5)

Pathway of the Current through the Body

The path followed by the current as it flows through the body is of prime importance in determining the injury. In general, if there are no vital organs in its path the resulting injury is negligible or confined to burns. (5)

Duration of the Contact

The greater the surface of contact and the longer its duration the more pronounced will be the effects of the current passing through the conducting body and the less the chances of recovery.

Phase of the Heart Cycle at the Instant the Shock Occurs

The susceptibility of the heart to fibrillate depends upon the phase of the heart cycle at the instant the shock is applied. (6)

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PHYSICAL REACTION TO VARIOUS CURRENT VALUES

The physical reaction to the wide range of current values may be grouped in eight classifications: (5)

1. Threshold of feeling.
2. Let-go current.
3. Freezing current.
4. Current producing unconsciousness.
5. Fibrillation current.
6. Nerve-blocking current.
7. Countershock current.
8. Excessive currents.

Threshold of Feeling

According to tests made by Dalziel and Lagen (7) the threshold of perception is about 1 milliampere when electrodes are held in the hands. A very faint tingling sensation is felt first; this increases rapidly in intensity as the current is increased, and, at the same time, there are involuntary muscular contractions of the hand and wrist.

In the threshold test for the 60-cycle alternating current, perception for 115 men was 1.1 milliampere average, 0.4 milliampere minimum, and 4.0 milliamperes maximum. For direct current the threshold perception for these 115 men was 5.2 milliamperes average, 2.2 milliamperes minimum, and 12.6 milliamperes maximum. (7) Data from numerous human accidents, although meager and inconclusive, seem to indicate that the proposed threshold values are conservative. It is Dalziel's (6) opinion that currents much in excess of the proposed threshold values must be considered very dangerous to human life.

Let-Go Current

The muscular contractions increase in intensity and progress up the arm to the chest with 10 to 15 milliamperes. From 15 to 20 milliamperes the contractions of the muscles are severe and painful, and a sensation of mental discomfort difficult to describe sometimes appears.

In tests by Dalziel (7) with the 60-cycle alternating current, the let-go currents for 114 men were 15.5 milliamperes average, 9.7 milliamperes minimum, and 21.6 milliamperes maximum. The limits of endurance for direct current for 28 men were 74 milliamperes average, 61 milliamperes minimum, and 83 milliamperes maximum.

Let-go tests were also conducted with direct current. Steady direct currents produced a sensation of internal heating of the hands and arms with only slight muscular contraction, however, severe muscular contractions were produced by sudden changes in current magnitudes, and a severe shock was experienced each time the circuit was broken. Many subjects stated they would almost rather maintain contact in spite of the burning sensation than experience the shock produced when they released the wire.

The maximum current that is safe for a man has been determined from a statistical study of the experimental results as 8 to 9 milliamperes for 60-cycle alternating current and at least 80 milliamperes for direct current. (7) The reasonably safe 60-cycle alternating current for most normal healthy adult women is about 6 milliamperes. (9)

Freezing Current

This is the current, greater than the let-go current, that will produce enough contraction of the muscles to hold its victim fast. This current is dangerous; blisters form in only a few seconds where it passes through the high resistance epidermis. The epidermis then loses its protective resistance, and the current increases in accordance with Ohm's law. Unless someone is present to break the circuit and release the victim, the result may be fatal. (5)

Current Producing Unconsciousness

According to Dalziel, (6) 60-cycle currents at the let-go level, that is 10 to 20 milliamperes from hand to hand, are painful and hard to endure for even a short time. If long continued they may lead to collapse, unconsciousness, and death. The physical condition of the victim is of prime importance in determining this hazard.

The maximum current that an individual can tolerate for a short period without losing consciousness lies somewhere between the freezing current and the current that will produce ventricular fibrillation of the heart. Its value lies between a freezing current of 15 to 25 milliamperes and the fibrillating current of 75 to 100 milliamperes. (5)

Fibrillation Current

From extensive experiments performed on animals, Ferris, King, Spence, and Williams (10) drew the following conclusions regarding the fibrillating condition:

> Currents somewhat greater than those just necessary to stop respiration by action on the muscles may cause fatalities, even though the duration of such shocks is but a few seconds or less - far too short to be important from the standpoint of interruption of respiration, and obviously too short to give any opportunity for rescue before the end of the shock. Death under such conditions is brought about by ventricular fibrillation, which is a disruption of normal heart action. This condition is an uncoordinated asynchronous contraction of the ventricular muscle fibers in contrast to their normal coordinated and rhythmic contraction. It results from an abnormal stimulation rather than from damage to the heart. In the fibrillating condition, the heart seems to quiver rather than to beat; no heartsounds can be heard with a stethoscope - the pumping action of heart ceases; failure of circulation results in asphyxial death within a few minutes.

In general, the fibrillating current is said (6) to be proportional to body weight. Similar variations were noted by Dalziel (6) while he was studying let-go currents, but all efforts to find a correlation with age, weight, strength of grip, or arm measurements were inconclusive; however, higher values were obtained on well-developed individuals having the appearance of good health. Other things being equal, it is believed (6) that let-go currents and fibrillating currents at least should be roughly proportional to size and weight.

Dalziel (6) found that for 0.03-second shocks the hearts of sheep seemed to be most susceptible to fibrillate at currents of about 6 amperes, and less sensitive as the current was increased or decreased from this value. The explanation is that high currents cause complete contraction of the entire heart musculature, and fibrillation is prevented. If the shock is of appreciable duration death is inevitable. However, if the shock is of short duration, when the current is interrupted, relaxation may be followed by spontaneous resumption of normal rhythmic contractions. It is believed (6) that abdominal massage and stimulation of the heart by artificial respiration may be beneficial is assisting the heart to regain its normal rhythm. This is offered as an explanation of infrequent accident cases in which victims apparently withstand relatively large currents.

Jellinek (11) found from experiments on anesthetized monkeys that after the heart went into ventricular fibrillation it often recovered normal rhythm spontaneously. He states that the condition definitely is reversible, at least in the primates, including man.

Nerve-Blocking Current

According to Kouwenhoven (12) one of the most common effects on the nervous system is the production of a temporary paralysis or block. The location of this block will depend upon the path taken by the current.

In a later article Kouwenhoven (5) has the following to say regarding nerve block:

> The block in the nervous system may be either in the cord connecting the fourth ventricle of the brain to the lungs or in the fourth ventricle itself. This block will prevent the lungs from receiving a signal from the brain, and normal respiration will cease. Artificial respiration should be started promptly in these cases.
>
> If the heart is not thrown into ventricular fibrillation by the shock, there is an excellent chance that nature will repair the block and that after a period of artificial respiration normal breathing will again assert itself.
>
> It must be kept in mind that both nerve block and ventricular fibrillation may result from the same electric shock. In such cases all that can be done in the field is to apply artificial respiration. It should be continued until either the victim is

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resuscitated or rigor mortis sets in. Wills Maclachlan reports a case of successful resuscitation in which artificial respiration was continued for 8 hours.

Countershock Current

Ventricular fibrillation may be arrested by the passage of a 60-cycle current of about 1.5 amperes directly through the heart. This current has enough value to bring the muscles of the heart to rest and hold that organ in diastole. When the circuit is broken the heart usually will resume its normal operating rhythm. The feasibility of this method of recovering the heart was demonstrated by experimenting with animals. It has been applied to man, and two cases of successful recovery of the fibrillating heart have been reported. Many hospitals are now equipped with apparatus for applying a resuscitating shock to the heart should fibrillation occur. (5, 12)

Excessive Currents

When contact is made with high-voltage circuits, very large values of current may flow. Such accidents usually result in severe burns, which heal slowly and without infection. In severe cases limbs or fingers may be lost, and death may follow as a secondary effect. (5)

The following table (13) summarizes the physical effects of contact with electricity of various current values:

HUMAN RESISTANCE TO ELECTRICAL CURRENT

Type of Resistance	Resistance Value, ohms
Dry skin	100,000 to 600,000
Wet skin	1,000
Internal body - hand to foot	400 to 600
Ear to ear	about 100

Current Values Affecting Human Beings

	Readings, ma.[4]	Effects
SAFE CURRENT VALUES	1 or less	Causes no sensation - not felt.
	1 to 8	Sensation of shock, not painful; individual can let go at will because muscular control is not lost
UNSAFE CURRENT VALUES	8 to 15	Painful shock; individual can let go at will because muscular control is not lost.
	15 to 20	Painful shock; muscular control of adjacent muscles lost. Cannot let go.
	20 to 50	Painful, severe muscular contractions; breathing is difficult.
	50 to 100 (Possible)	VENTRICULAR FIBRILLATION (A heart condition that results in instant death - no known remedy.)
	100 to 200 (Certain)	
	200 to over	Severe burns, severe muscular contractions - so severe that chest muscles clamp heart and stop it during duration of shock. (This prevents ventricular fibrillation.)

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[4] 1 Milliampere is 1/1000 ampere.

FORMULA

$$\text{Current through body} = \frac{\text{Voltage applied to body}}{\text{Resistance of body and contacts}}$$

The severity of a shock depends upon the following factors:

1. Increase in voltage.
2. Amount of moisture on contact surfaces.
3. Increase in pressure of contact.
4. Increase in area of body contact.
5. Resistance of body portions.

Three factors involved in electric shock:

(Electrical)	Voltage	(Water analogy)	Pressure forcing water in pipe.
	Current	do.	Water in pipe doing work.
	Resistance	do.	Something in the pipe tending to hold back the water from flowing.

Practical Problem:

A worker with wet clothes or wet with perspiration comes in contact with a defective 120-volt light cord and establishes a good ground.

		Ohms
(Look at chart)	Wet skin resistance	1,000
	Internal resistance	500
		1,500

(Use formula) Current through body $\frac{120 \text{ volts}}{1{,}500 \text{ ohms}} = 80$ ma. (Note that muscular control is lost and that he cannot break contact.

As the contact is continued the skin resistance is reduced. If the skin is punctured the skin resistance may then be disregarded.

Now for practical purposes the total resistance of the worker may be in the neighborhood of 600 ohms.

(See chart) Current through body $= \frac{120 \text{ volts}}{600 \text{ ohms}} = 200$ ma. (Certain death

PHYSIOLOGICAL EFFECTS OF ELECTRIC SHOCK

According to Kessler (14), the strength and character of the current are not the sole factors in determining the intensity of the injury. The range of individual susceptibility is great, and it varies in the same individual on different occasions.

Electricity produces two effects - heat and stimulation. When electricity finds resistance in the path of its movements, it creates heat in the body offering resistance. If the current is high and the resistance great the conductor is destroyed. The body tissues offer varying resistances to the passage of current. The resistance of dry skin is high - 100,000 to 600,000 ohms; if the skin is wet the resistance is low - 1,000 ohms. The effects of heat are important when burns occur, because the penetrating effects destroy the blood vessels that nourish the affected part. The effects of heat are found in the tissues that offer the greatest resistance - the point of entrance into the skin and the point of exit from it. If the skin is wet there may be no marks in a fatal electrocution. (15)

According to Jellinek, quoted by Kessler (14), injuries actually owing to electricity are not true burns; only an arc light can produce burns. Wounds from an electric shock are generally grayish-white, circular and firm, and without a trace of reactive inflammation in the adjoining area. The hairs next to the wound are not even singed, and the wounds are not in the least painful. There is not always a continuous lesion and almost never a severe or suppurating infiltration of the surrounding area - not even in injuries of the bones and joints. After a latent stage, possibly of several weeks, an aseptic necrosis sets in without any general manifestations, even though there has been extensive loss of substance or so-called spontaneous amputation. If such injuries are treated conservatively the prognosis is very good. Surgery is contraindicated for two reasons: 1, During the first few days, or even weeks, it is impossible to determine the extent to which degeneration of the tissues may occur; 2, the vessel walls, even at some distance from the electrical injury, sometimes are very vulnerable, so that severe hemorrhages may be induced. Scar tissue from electrical burns is soft, vascular, and never shrinks, and is thus very favorably constituted.

What is termed "death from electricity" is in reality only apparent death. Necropsy reveals only terminal phenomena, such as edema of the brain or lungs and extravasations, but no explanation for the fatal outcome is found. Jellinek (14) thinks that disturbances of function of the vital organs causes death. Support for this belief is found in the fact that persons who survive electrical accidents never show evidence of loss of organs even when they have lain like dead for hours. If the patient recovers his restoration is rapid.

The following effects that may result from electric shock are mentioned by Kouwenhoven (12):

> The passage of an electric current through the body produces numerous effects that differ not only in intensity, but also in kind. They range all the way from a slight tingling sensation to death. The consequences depend upon the value, frequency, and pathway of the current and on the duration of the shock. The aftermath may be good or evil. An electric shock may produce healing in certain mental diseases or it may produce a state of depression of the vital processes of the body characterized by rapid but weak pulse, rapid but shallow breathing, pallor, restlessness, and a depressed mental state similar to surgical shock or a highly excited, almost maniacal state. Some of the effects produced by an electric current are discussed in the following.

If the victim of an electric shock retains consciousness during and following the contact, there is often a whistling or ringing in the ears and partial deafness for a time. In addition there may be visual disorders such as flashes and brilliant luminous spots. Pain and soreness of the muscles are a common reaction. If the shock is a severe one, the victim usually will be restless and irritable. These disorders generally disappear in a few hours.

Convulsions may occur in cases of electric shock. They usually are characterized by irregular muscular spasms and tremors.

Blood Pressure

The blood pressure rises suddenly when contact is made with a high-voltage circuit because of the severe muscular contraction. When the circuit is broken, the pressure usually remains high for a period due to the rapid heart rate provided that organ is not injured by the shock.

Hemorrhages

Hemorrhages usually petechial in nature, sometimes are found in the brain, the nervous system, and other organs. One or both eyes may be bloodshot following a shock owing to the rupturing of blood vessels in the conjunctiva. Gross hemorrhages have been found in the fourth ventricle of the brain upon autopsy.

According to Hyslop (16), it has been demonstrated that the effect of electric current on the blood vessels directly traversed is such that degenerative changes in surrounding tissue may be slow in development. It is known that electrical superficial burns may seem inconsequential at first, but that, owing to delayed effects there may be extensive necrosis of the injured tissues later.

If current traverses the cervical sympathetic, it is not unlikely that the brain vessels may be affected. When the splanchnic and abdominal sympathetic ganglia are violently stimulated, there may be spread of the impulses to the cervical sympathetic, and brain vessel reaction could occur. There might be immediate transient symptoms of focal nature if the brain vessel effects were limited to brief spasm. If the vessel wall were to suffer structural damage with impairment of permeability, effects on surrounding brain tissue might be delayed so that focal clinical symptoms would not be evident for even a few days.

The Nervous System

The nervous system may be so profoundly shocked or fatigued by contact with an electric circuit that it cannot function normally again for a period of minutes or hours. The nerve cells are injured, especially in areas that have been traversed by the current. Injured cells are characterized by a dark shrunken nucleus, which is often eccentric in position, and the loss of granules. The damage, however, is patchy in distribution so that injured and normal health cells lie in close proximity. Autopsies of shock victims also have revealed cavities in the nervous system of 25 to 200 microns in diameter. These may be caused either by heat or electrolysis.

One of the most common effects of electric shock on the nervous system is the production of a temporary paralysis or block. The location of this block will depend upon the path taken by the current. The lungs or other portions of the body may be paralyzed following the shock.

Mental factors seem to play some part in the effects experienced by violent shocks. Experiments by Jellinek (11) indicate that a person who is prepared for the shocks can contact high voltages that commonly kill people without suffering any harm. He (11) is unable to explain why preparedness so profoundly alters the effect of an electric shock.

TREATMENT FOR ELECTRIC SHOCK

Artificial Respiration

Jellinek states (11) that, in the first place, every apparently lifeless victim of an electrical accident must be regarded and treated as capable of resuscitation, however hopeless the case may seem. Second, resuscitation must be immediate without waste of time in carrying the victim about or trying to listen to heart sounds. The prime need is to ensure a supply of oxygen to the tissues to keep them viable (capable of living), which means that steps must be taken to help the patient's respiration and circulation. According to this authority the rate of success in resuscitation of people who meet with such accidents is no better today than it was 50 years ago. In his opinion there are two main reasons for this: Artificial respiration as generally practiced is often a menace rather than a help, and there still is lamentable confusion among many physicians as to when a person is really dead. Failure of the pulse is still generally considered to be conclusive evidence of death. However, a victim of an electric shock may be alive even though his pulse and breathing have stopped. There is a definite period after the obvious signs of life have disappeared when active processes still go on in the body. During this period, or at least the early part of it, the victim may be saved by proper methods of resuscitation.

Jellinek (11) describes the signs of death as follows:

> What are the final and unanswerable signs of death? There are just a few, and they have been known for a long time. One is the gravitational effusion of blood from the relaxed body that lie lowermost, usually the back, into the tissues. About half an hour after death many bluish spots appear under the skin, gradually increasing in size. This produces the characteristic lividity of death. Another sure sign of death is rigor mortis, a tightening of the muscles which manifests itself as stiffness of the joints and springiness in the ankles. The time of appearance of rigor mortis after death is very variable.
>
> Everyone who applies artificial respiration to a drowned or electrocuted person should understand these conclusive indications of death and accept nothing less as a sign that no more can be done.

In 1905 Jellinek (11) concluded that before these signs appear the victim of an electric shock or drowning may be in a state of suspended animation. The chief basis of this idea was the autopsy findings, which in many cases were really quite incompatible with immediate death.

Jellinek (11) discusses some of the requirements of artificial respiration as follows:

> Any method of artificial respiration, if carried out properly, can serve the purpose of providing adequate lung ventilation, but in the hands of over-enthusiastic lifesavers some methods are more dangerous than others. The dangers arise chiefly from misguided efforts to pump the maximum amount of air in and out of the lungs. This consideration has tended to obscure some of the physiological requirements in normal respiration and circulation.
>
> In normal breathing the active phase, as far as the muscles involved are concerned, is inspiration, i.e., expansion of the chest. Expiration is largely passive, a matter of elastic rebound. Hence in artificial respiration we must devote our active effort to expanding the chest rather than compressing it. Besides the desirability of emulating the normal breathing process, there is another important reason for not compressing the chest. Inside the thorax there exists a precariously balanced system of varying pressures, any upset of which will affect the functioning of the heart and lungs. To put it more precisely, any active compression of the chest will be transmitted to the great veins leading to the heart and will impair the return of blood to the heart. On the other hand, anything that expands the chest will lower pressure inside and assist the return of blood to the heart as well as the vital coronary circulation itself.
>
> This method of artificial respiration, which we believe is the method of choice, is the one originated by the London physician Henry Robert Sylvester in 1858. In it the patient lies on his back and the person administering the treatment briskly and rhythmically stretches the arms and shoulders outward and then allows them to fall back beside the chest. The only disadvantage of this method is that of all supine positions: the tongue tends to slip back and to block the upper respiratory passages. The tongue must therefore be kept pulled forward by some contraption: e.g., a safety pin stuck through the tongue and tied with string to the victim's neck. On the other hand, the supine position allows free inspection of the face and neck for signs of returning respiration, such as swallowing movement. It is to be preferred to all techniques that involve compression of the chest, including the famous and widely used Schaefer method, invented at the beginning of this century by the British physiologist Sir Edward A. Sharpey-Schaefer.
>
> We have shown quite clearly in experiments that the dangers of bad artificial respiration are very real. It is easy to kill

an animal in 1 or 2 minutes by excessive compression of the chest. Death is much more rapid than from ordinary asphyxia; it is accompanied by signs of cerebral irritation, by very acute edema of the lungs and brain and by blood clots, which at autopsy are found attached to the inner walls of the heart and the blood vessels. These experimental post mortem findings are only too reminiscent of the actual changes sometimes found in human victims of faulty or unnecessary artificial respiration - not to speak of fractured ribs and ruptured spleens, livers and diaphragms.

Any electric current may be dangerous, and accidents from electricity are common in and around mines. In all cases the victim should be removed from contact with the live wire or conductor, and if he is not breathing artificial respiration should be started at once.

During the period July 1, 1910, to June 30, 1951, the Safety Division of the Bureau of Mines trained 1,708,088 persons in first aid, including administration of artificial respiration.

The most frequent conditions under which artificial respiration is required are electric shock, gas poisoning, drowning, and suffocation from various causes. It has been estimated that 12,000 deaths occur each year from these causes, but that 40,000 to 50,000 lives are saved annually by application of artificial respiration, with the use of the oxygen inhaler where available.

The Schaefer (prone-pressure) method and the Sylvester method of artificial respiration are recommended by the Bureau of Mines. (17) The prone-pressure method being the simpler and easier to perform should be used in all cases where possible. However, there may be a few instances where the Sylvester method is more satisfactory. Detailed illustrated instructions in the performance of the Schaefer and Sylvester methods of artificial respiration are given in Bureau of Mines Manual of First Aid Instruction. (17)

The recent failure to resuscitate a man working on a line on the surface at a mine in West Virginia calls attention to the value of the application of "pole-top" resuscitation. The victim in this instance was removed to the ground before artificial respiration was started and did not revive. Pole-top resuscitation, sponsored by the Edison Electric Institute (18), is a technique by means of which artificial respiration may be given to a lineman who, while working on a pole, receives an electric shock that suspends normal respiration. Aid can thus be given immediately without the delay of lowering the victim from the pole in order that he may be laid in the prone position.

Pole-top technique for administering artificial respiration is as follows (18):

The first person to reach the victim clears him from electrical contact, letting him hang alongside the pole from the safety strap.

The operator (one who will administer artificial respiration) takes a position on the pole below the victim, and after placing his safety strap around the pole (at a point above the victim's

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spurs) proceeds to work his way upward with one leg of the victim on either side of his safety strap, and with the victim's body between himself and the pole. Tools which may interfere with resuscitation or injure rescuer should be removed from the victim's belt. When the safety strap is as high as possible between the legs of the victim, the victim is held in a straddle position on the operator's safety strap. The operator takes a step up and places victim in position for resuscitation. The victim's safety strap should remain around the pole and can be effectively used by operator as an aid in keeping victim in desired position. It should not be unsnapped or cut until the victim is to be lowered or is effectively supported by a hand line.

If the victim's mouth can be quickly examined it should be cleared of foreign substances and the tongue pulled forward to clear the air passage. No time should be wasted on these details. The head should then be pushed slightly forward.

The operator encircles with his arms the waist of the victim (underarm), placing both hands on the abdomen, thumbs below the lower ribs and fingers touching.

With his arms and hands, the operator compresses the victim's abdomen in an upward motion. At the finish of the stroke, the hands are cupped with the fingers depressing the abdomen under the breast bone. The pressure is then quickly released and reapplied at a frequency of 12 to 15 per minute, until the victim regains consciousness or is to be lowered to the ground.

The object of the pole top technique is to raise the abdominal organs against the diaphragm in a manner such that pressure will be exerted on the diaphragm uniformly across the body. Extreme pressure must be avoided and localized pressure in the center is undesirable and will lessen the effectiveness of the resuscitative effort. The cupping of the hands is to prevent the hands sliding apart and off the victim and is not for the purpose of giving localized center pressure. The arms should gently but firmly restrain the outward movement of the abdomen at the sides.

Pole-top resuscitation is intended to supplement the prone pressure method and is for use as an emergency measure where it is impossible to place the shock victim in the prone position quickly.

Administration of Drugs

Drinker (19) called attention to the common practice of doctors to give some sort of hypodermic injection to patients overcome by carbon monoxide, close to death from submersion, or in desperate straits from electric shock. He considers, especially, the question of whether any drug can be administered that will improve the chances for reviving the breathing at once or aid the condition of the circulation in electric shock. After discussing several possible drugs that have been shown by animal experimentation to stimulate breathing, he concludes that "at the present time there is no substance which can be given by injection which benefits the breathing significantly."

Regarding stimulants to the heart and circulation, Drinker has the following to say:

> The condition of the heart and the blood circulation as a result of electric shock is far better understood than was the case even a few years ago. Divested of all the medical description possible, it seems to me that the following circulatory derangements may be met:
>
> 1. The shock, by passing through the medulla, may have stopped the breathing and left the circulation of the blood somewhat impaired but not seriously so. This is the ideal case for resuscitation. But if four or five minutes of absent breathing intervene before artificial respiration is started, the heart and blood vessels will begin to show the effects of oxygen lack. Oxygen will remedy this condition, and no injection or treatment other than artificial respiration is required or advisable.
>
> 2. The medulla, in addition to the breathing center, contains in very small space the centers for regulating the heart rate, particularly for slowing the heart and for regulating the blood pressure by controlling the caliber of the smallest blood vessels. One may thus expect that a shock which stops breathing can readily affect nearby units concerned with the circulation. This occurs and, consequently, the situations resulting may be quite varied. Let me list a few of them:
>
> (a) Breathing may be absent and the heart very slow and weak with low blood pressure.
>
> (b) Breathing may be present, the heart slow and the blood pressure variable but becoming low.
>
> (c) Breathing may be irregular with a tendency to stop, the heart slow, irregular and weak, and the blood pressure low.
>
> Obviously, these possible situations may vary between themselves so that in each case the condition of the circulation can be appraised only by a competent physician. By "competence", I mean a man capable in cardiology and with at least some knowledge of the consequences of electric shock. Very few doctors meet this last mentioned requirement, and consequently the treatment given such patients is not, to say the least, discerning.
>
> Artificial respiration for absent or inadequate breathing is, of course, essential, since lack of oxygen will make the condition of the circulation grow worse rapidly. If breathing is feeble and unreliable, oxygen-carbon dioxide inhalation is helpful. Absolute rest is imperative.

If the blood pressure continues to remain low and the heart feeble so that the patient begins to be in danger for circulatory inadequacy, the physician may consider giving an intravenous injection of a small dose of epinephrine or ephedrine. In either case the injection should be given very slowly and should be understood to be a last resort. Caffeine and sodium benzoate, discussed in the section on breathing, should have been given early in the management of the case and will benefit the circulation.

3. The shock by passing through the heart may cause ventricular fibrillation. The patient is dead white, not bluish. No pulse can be felt and after three or four breaths respiration ceases. Such patients are often given injections of epinephrine through the chest wall directly into the heart.

There is increasing evidence that ventricular fibrillation occurring spontaneously in man, though usually fatal, occasionally ceases with return of the heart to normal rhythmic beating. There is no reason to believe the same thing may not happen after electric shock, but such an event must be very rare.

There is no practical procedure which affects the fibrillating heart muscle, and an intracardiac injection of epinephrine can be relied on to do but one thing, namely, make fibrillation worse, so that any change of spontaneous shift to normal pulsation is lost.

PREVENTION OF ELECTRIC SHOCK IN MINES

Measures for the prevention of electrical accidents in mines are described in numerous Bureau of Mines publications. These measures are summarized more or less completely in the form of questions and answers in Bureau of Mines Coal Miners' Safety Manual.

Under the heading, Big Coal Mining Hazards - Electricity, the magazine Coal Age (20) gives the following measures for the prevention of electrical accidents in coal mines:

> Proper guarding of bare conductors, use of insulating mats or platforms, inclosure of transformers, converters, motor-generator sets, rectifiers and other electrical and control equipment.
>
> Use of atomatic circuit breakers for every section of mine so that in case of a short circuit, extreme overload or ground that that section will be isolated automatically.
>
> Sectionalizing switches to cut off current from parts of mine not being operated.
>
> Use of inclosed or otherwise protected switches, starters and controls.

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Thorough grounding of electrical equipment and electrically operated machinery, including use of separate ground wires in trailing cables.

Use of shielded cables with ground wires, particularly for high voltages.

Use of safety taps with adequate fuses on trolley line.

Regular inspection and maintenance in good condition of electrical equipment and electrically operated machinery.

Regular inspection and reconditioning of trailing cables. Temporary splicing done carefully so as to make cable as effective electrically and as strong as a new cable, and the number of such splices before vulcanizing or other reconditioning strictly limited.

Provisions for automatic closing of doors of transformer rotary-converter, motor-generator and rectifier rooms in case of fire.

Ventilation of transformer, motor-generator, rotary-converter, rectifier and charging stations with intake air passing through station to return at a point sufficiently remote from timber sets and shaft timber that it will not involve those should an electric fire be started.

Well bonded and cross-bonded track to prevent stray currents, sparking at rail connections and also heating of equipment because of inadequate voltage at machine motors.

Care to scale roof by which electrical conductors are to be supported and to have clamps as near as may be in line and level.

No men working on "live wires" even when voltage is low.

Locking of switches on the "off position" by all operatives when working on a power line, with the switch between operative and source of power.

All power wires cut off when timbers are being set over or near electric wires.

Trailing cables wound in the form of a figure of eight to prevent excessive heating and when not in use disconnected from the machine and switches unless the switch can be locked in the off-position.

All electrical equipment put in safe condition or taken out of service before being left at the end of the day.

Training in first-aid and resuscitation to prevent injuries or shocks from becoming fatalities.

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Proper training of men who have to install, repair or handle electrical equipment.

Trolley wires carefully guarded where less than 6-1/2 feet above rail, especially at points where they cross the track; at switches also and at places where men embark and disembark from mine cars, as also in other places where men must work or pass under such wires.

Suspension of trolley wire on opposite side of track to that on which clearance is provided.

Hard hats to protect wearers in case of contact with "live wires."

Use of shoes having non-conducting soles and "hard toes" by all persons working on or around portable electric equipment.

Use of approved insulating gloves by all men whose duties require them to handle trolley poles, trailing cables or wires by which connections are made from portable equipment to power sources.

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